CALIPER2012

The CALiPER program has tested more than 500 products since its inception in 2006, revealing a variety of performance trends, holding manufacturers accountable for claims, and identifying concerns that limit adoption. Over the past six years, the LED marketplace has changed substantially; previously relegated to niche status, LED products are now a viable alternative in many product categories and market share is expected to grow rapidly. This document summarizes recent testing results and provides an overview of multi-year trends.

2012 CALIPER Reports

Starting in 2012, each CALiPER report focused on a single product type, a departure from the previous approach of conglomerating numerous types of lamps and luminaires into a single summary report. By virtue of focusing on a specific product type, each application summary report provides in-depth analysis of the performance baseline established by conventional products and the resulting expectations for LED products. The LED product types examined in 2012 include downlight retrofit units, floodlights, BR30/R30 lamps, AR111/PAR36 lamps, wallwashers, linear pendants, and PAR38 lamps. CALiPER summary reports, as well as detailed data for each product tested, are available at http://ssl.energy.gov/caliper.html. In addition to the standard reports, in 2012 CALiPER also published the second installment of a study focusing on lamps available at retail stores. For the year, CALiPER reported on 150 unique products.

Products tested by CALiPER are selected with the intent of capturing the current state of the market, but the selection does not represent a statistical sample of all available products. Nonetheless, when evaluated as a whole, the CALiPER test results from 2012 provide valuable insight into the rapidly changing state of LED technology in general illumination applications.

Long-Term Performance Trends

One prominent role of the CALiPER program has been to track performance trends from year to year. Although it is not statistically meaningful data, the compiled figures reveal key trends in the development of LED technology. One of the most obvious changes has been the increase in luminous efficacy, with the average and maximum rising each year between 2006 and 2011, although low efficacy products were also tested. In 2012, the

mean efficacy dropped somewhat to an overall average of 52 lm/W¹ (Figure 1). Some of this small reduction—the average was 55 lm/W in 2011—can be attributed to the inclusion of recessed downlight wallwashers, a product category for which efficacy is generally lower because greater optical control is required. It is also possible that manufacturers have identified the 45–60 lm/W range as an optimum balance between price and performance, as evidenced by trends towards reduced variability; the range for the 25th to 75th percentile was 47–59 lm/W in 2012. The noted range is just above the ENERGY STAR® and DesignLights™ Consortium Qualified Products List qualification level for many product categories, although much higher efficacies are possible.

Similar to efficacy, the color quality of CALiPER-tested products—as quantified using CRI—has shown an increasing trend over the past seven years, with reduced variability (Figure 2). An increased availability of appropriate CCTs has also been noted, but because CCT is heavily influenced by CALiPER selection parameters, it has not been charted over time. Importantly, the improved color quality of LED products may also be contributing to the slowing trend of increased efficacy; that is, more manufacturers are emphasizing quality, rather than just energy efficiency.

Considered separately, the testing results for integral LED lamps also show some notable trends. In particular, there was a substantial increase in mean input power in 2012 compared to the two previous years (Figure 3). Given that efficacy remained mostly constant (Figure 4), this allowed for much greater lumen output (Figure 5). It is plausible that some of this increase is a consequence of the CALiPER selection process, but it also mirrors other observations.

2012 General Observations and Remaining Challenges

Across the variety of product types examined by CALiPER, there are many common observations. Foremost, the variability in performance for LED products is considerable, as best evidenced by the four-fold difference between the lowest and highest efficacy products purchased by CALiPER in 2012—the same trend exists within any given product category. Similarly, there is a wide range of lumen output and color quality attributes; these may result from different performance needs, but could also arise from disparities in product quality. Especially for luminaires, LED product manufacturers sometimes lack a clear performance target from the conventional lighting market because the range of products is vast. Nonetheless, there are LED products in every category tested in 2012 that could be considered best in class compared to any conventional light source, including

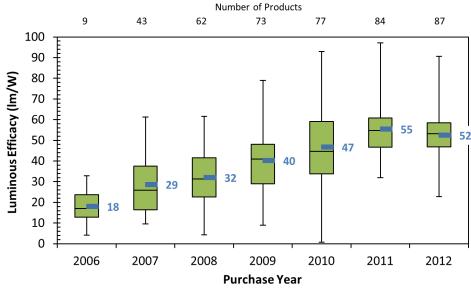
¹ Long-term performance trends, including Figures 1–5, are based on the purchase year for each product, which may be different from the year in which the data was published.

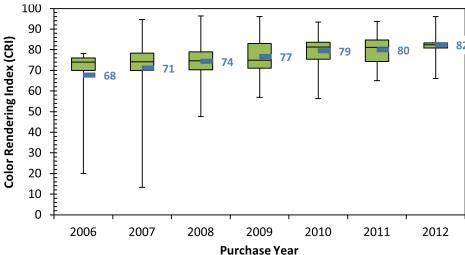
incandescent, fluorescent, or high-intensity discharge.

Despite the presence of very high performing products, one challenge that potentially limits the specification of LED products is that they often do not replicate the modularity of conventional products. Traditional luminaires can be fitted with different lamp and ballast combinations, and are usually available with several different trim and accessory options. These features allow fine-tuning of lumen output, color, and distribution in order to meet specific needs. In contrast, the LED luminaires examined by CALiPER in 2012 were much less likely to be available in more than one lumen package, or to have a variety of accessories. This is potentially a consequence of the rapid development of LED products, which are often updated on a yearly cycle.

Similarly, a type of integral LED lamp from a given manufacturer (e.g., PAR38) may not be available in more than one lumen package. In general, lumen output for integrated LED lamps has increased, but the lower output products are typically phased out, leaving a void. Although it is possible to find a product at any given beam angle and with lumen output approaching that of a 100 W incandescent lamp, it is more difficult to create an ensemble of LED lamps to meet multiple needs within a space. Intermixing lamps from multiple manufacturers may result in poor color consistency because even lamps with the same nominal CCT can appear different. Nonetheless, it is important to note that a vast majority of currently available LED products have a color appearance similar to the conventional lamps with which consumers are familiar, and render colors at a level that is generally considered acceptable for typical applications (i.e., CRI greater than 80).

Selecting a lighting product comes down to matching performance with a given application. In terms of the primary attributes tested by CALiPER—energy use, color quality, light output, power factor, distribution of light—many LED products meet or exceed the performance of other alternatives. In some places where high output is needed, LED products are not yet available, but this threshold is constantly increasing. Secondary factors, such as flicker, dimming, and electronic compatibility—areas of concern for some LED products—should also be considered when choosing products, although





Figures 1–2. Yearly changes in measured luminous efficacy and CRI for CALiPER-tested LED products. Note that these plots are grouped by product purchase year, whereas previously published plots were grouped by report year. Further, they do not include data from additional testing of certain products, such as in situ configurations, and the listed number of products does not include benchmark tests of conventional products.

these are more difficult for CALiPER to analyze because standard measurement and reporting procedures do not exist. Ultimately, cost is often the driving factor in decisions about lighting. Regular CALiPER reports do not include cost data, but price is a key element of the investigations of lamps sold in retail stores. Those results indicate substantial price reductions in the last year, although the initial cost of integrated LED lamps is likely still higher than other alternatives. At the same time, the lifetime cost is often less because the products are usually more efficacious and/or last longer. In the end, a careful analysis of many factors is necessary to

make an informed decision; generalizing the performance characteristics of light source types is ill advised.

Maximum

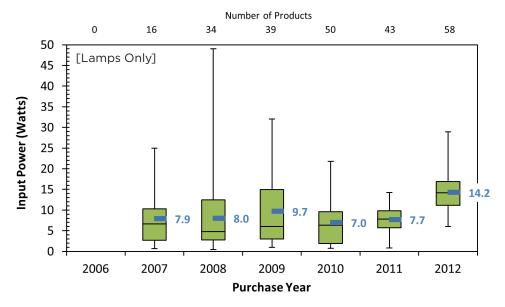
Mean

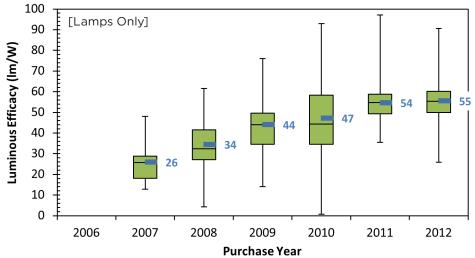
Median

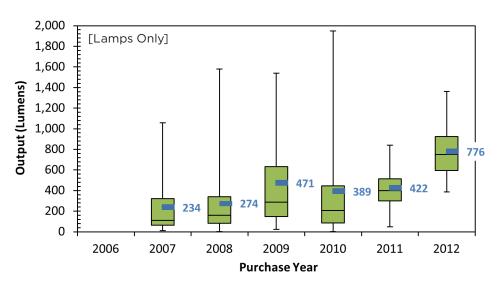
75th Percentile

25th Percentile

Choosing the right product for an application requires accurate information. One of the primarily roles of the CALiPER program has been to promote accuracy in product literature by evaluating manufacturer claims. Although performance continues to improve, CALiPER still finds numerous manufacturer claims that are more than 10% different from the measured value. These discrepancies are more likely to be found with metrics related to input power and light output, and less likely with color quality attributes. For







Figures 3–5. Despite little change in efficacy, the typical input power and lumen output of integrated LED lamps saw a substantial increase in 2012. Note that no LED T8 lamps were purchased by CALiPER in 2011 or 2012, which accounts for the lower measured maximum output.

example, approximately two-thirds of the products reported on in 2012 had measured lumen output within $\pm 10\%$ of the manufacturer's claimed value. Of the remainder, an equal number had output greater than or less than the CALiPER tolerance. These discrepancies could be due to inaccurate specification sheets or packaging, literature not keeping pace with product updates, or differences in manufacturing runs. They likely also depend on how each manufacturer selects a value to report, which could be the low end of the distribution, the mean, the high end, or just a single random test value. Adding to the confusion of manufacturer claims are values on product labels, specification sheets, packaging, and/or LED Lighting Facts data that do not match. Regardless of the cause, accuracy in reporting remains a concern.

Conclusions

Compared to past years, increases in efficacy slowed in 2012, and other factors, like CRI, showed signs of stabilizing. However, CALiPER data also suggest that price is being reduced and the lumen output of integrated LED lamps is increasing. It is important to remember that the product types tested by CALiPER vary from year to year, which can mask trends. Nonetheless, with a majority of conventional products—excluding some high-output products—now having an LED alternative, manufacturers may be focusing on reducing initial cost, or on improving lighting quality, rather than increasing efficacy to reduce life-cycle cost. In general, while LED products have come a long way since 2006, advances in efficacy, quality, control features, and cost effectiveness should continue.



Energy Efficiency & Renewable Energy

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